Numerical Simulation of Load-Following Operation for APR1400

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1. Introduction

A model predictive control (MPC) method is applied to APR1400 reactor power controller for power level and axial power distribution controls. The model predictive control methodology [1-2] has received much attention as a powerful tool for the control of industrial process systems.

In this paper, rapid step change and daily load follow operations are numerically simulated by MASTER[3]. The results of numerical simulations to check the performance of the proposed controller represent that the power level controlled by the controller could track the target power level effectively, satisfying all constraints. .

2. Methodology

The basic concept of the MPC is to solve an optimization problem for a finite future at current time and once a future input trajectory has been chosen, only the first element of that trajectory is applied as the input to the plant. At the next time step, new values of the system output are measured, the control horizon is shifted forward by one step, and the same calculations are repeated. The purpose of taking new measurements at each time step is to compensate for unmeasured disturbances and model inaccuracies, both of which cause the measured system output to be different from the one predicted by the model.

In order to achieve fast responses and prevent excessive effort, a performance index for deriving an optimal input is represented by following quadratic function:

$$J = \frac{1}{2}\sum_{j=1}^{N}\left(\hat{y}(t+j\,|\,t) - w(t+j)\right)^T Q\left(y(t+j\,|\,t) - w(t+j)\right) + \frac{1}{2}\sum_{j=1}^{M}\Delta u(t+j-1)^T R\Delta u(t+j-1), \quad (1)$$

subject to constraints

$$\begin{cases} \hat{y}(t+N+i) = w(t+N+i), & i = 1,\cdots,L \\ \Delta u(t+j-1) = 0, \quad j > M & (M < N) \end{cases}$$

where $\hat{y}(t+j\,|\,t)$ is an optimum j-step-ahead optimal prediction of the system output (power level) based on data up to time t. The vector, w, is a setpoint sequence for the output vector and Δu is a control input change (R5 control rod position change) between two neighboring time steps. Q and R weight particular components of $(\hat{y} - w)$ and Δu at certain future time intervals, respectively. N is the prediction horizon and M is the control horizon. The prediction horizon represents the limit of the instants in which it is desired for the output to follow the reference sequence. There are two constraints. The first constraint, $\hat{y}(t+N+i) = w(t+N+i),\ i = 1,\cdots,L$, which makes the output follow the reference input beyond the prediction horizon, guarantees the stability of the controller. The second constraint, $\Delta u(t+j-1) = 0$ for $j > M$, means that there is no variation in the control signals after a certain interval $M < N$.

The reactor dynamics is described by the controlled auto-regressive and integrated moving average (CARIMA) model and the predicted outputs can be derived as a function of past values of inputs and outputs and of future control signals. Equation (1) can be solved by using the Lagrange multiplier technique.

$$A(q^{-1})y(t) = B(q^{-1})\Delta u(t-1) + D(q^{-1})v(t-1) + C(q^{-1})\xi(t) \quad (2)$$

Where $y \in R^n$ is the output(n=the number of outputs), $\Delta u \in R^n$ is the control input change between two neighboring time steps(m=the number of inputs), $\xi \in R^n$ is a stochastic noise vector sequence with zero mean value, and q^{-1} is backward shift operator, $A(q^{-1})$ is monic matrix, $B(q^{-1})$ is n x m polynomial , and $D(q^{-1})$ is n x 1 polynomial as a disturbance .

The number of outputs is two and the outputs consist of the power level and the ASI. The number of inputs is also two and the inputs are the axial positions of two types (regulating control banks and part-strength control banks) of control rod banks.

The reactor core dynamics changes according to reactor power, a variety of control rod positions, and so on. In order to reflect these various conditions and nonlinear characteristics, it is required to estimate the reactor core dynamics every time step. Therefore, the parameter estimation algorithm is used to identify the system dynamics every time step. This identified system model is used to solve the control problem.

3. Application to APR1400 reactor

The numerical simulation was performed to rapid step change and the load-following operation of APR1400 which was modeled numerically by MASTER code [3].

Figure 1 and 2 show the numerical simulation results for rapid power change and daily load-following operation, respectively. It was applied for simulation that ±10% step change and a daily load cycle of a typical 100-50-100%, 2-6-2-14hr pattern. Allowable ASI band was set to ±3% band from the ASI of 75% power equilibrium xenon state. It is shown that the reactor power follows well the desired reactor power and also the ASI remains inside the specified ASI band.

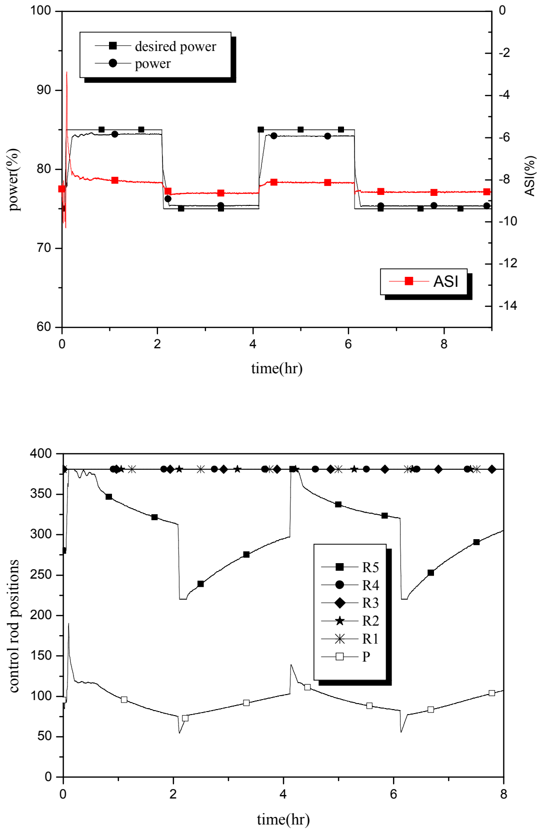
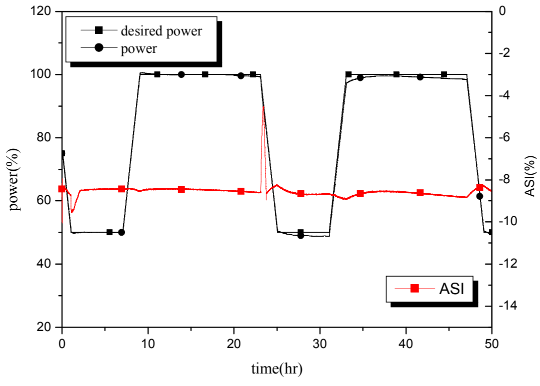


Fig. 1. Simulation results for rapid step change at 400EFPD.



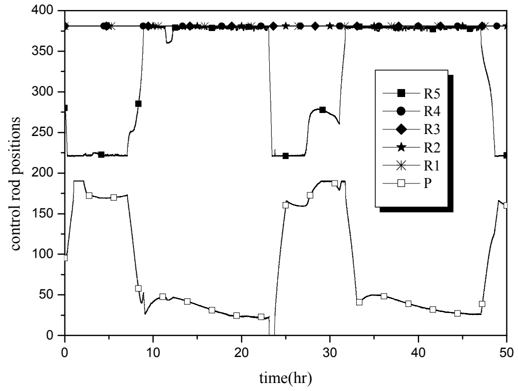


Fig. 2. Simulation results for load-following operation at 400EFPD.

4. Conclusion

In this work, we presented a MPC controller to control the power level and maintain the ASI in a specified ASI band for rapid step change and load-following operation of APR1400. An MPC method is combined with a parameter estimator to additionally take into account the change of operating points and the time-varying characteristics. It was known from numerical simulations that the MPC controller can handle the reactor power very well and also maintains the ASI in the specified ASI band.

Acknowledgements

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